# PUPIL DIAMETER VARIATION IN A VISUAL INTERPRETATION TASK

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# NAVAL POSTGRADUATE SCHOOL
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# THESIS

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IN A
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by

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## ABSTRACT


An indirect measurement of mental effort in interpreting an aircraft instrument was made using changes in pupil diameter and the latency of dilation as measures. Significance was found in latency of dilation across levels of interpretation difficulty, while no significance was found for percent changes in pupil diameter.

Results also showed a moving base-line pupil diameter for all subjects across trials suggesting arousal decrement for the first half of the experiment, with a lesser effect for the latter half of the experiment.

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# I. INTRODUCTION

Although pupillary variations evoked by emotional state and mental activity have been observed and commented on for at least two hundred years, large-scale scientific investigation of the phenomenon did not begin until the work of Hess and Polt (1960). Since that time, a rash of work has been done in an attempt to define the dimensions of the phenomenon.

The physiology of the eye and the visual processing system is, needlessly to say, an exceedingly complex and, as yet, largely unexplored area. Adler (1970) describes the visual pathway in terms of a three part chain lining the eye to the visual centers in the occipital cortex. The first two links are contained within the retina itself, beginning with the bipolar cells whose dendrites connect with the photoreceptors and whose axons synapse with the dendrites of the ganglion which compose the second link. This second neuron then connects with the last link, the lateral geniculate body (LGB). The visual messages are then transmitted to the cortex. Although the LGB can be viewed as merely a way station, there is evidence to indicate that some additional inhibitory activity reaches the LGB from the cortex that results in a modification of the retinal impulses; that is, the LGB adds its own counterpart to the messages it receives from the retina and transmits this in altered form to the cortex.

Adler (1970) further notes that in man, all of the visual fibers terminate in the striate area (area 17) located in the occipital cortex. This is the primary visual cortical area. The impulses received by this area enables one only to see, that is, perceive form and color. Other parts of the brain perform the tasks of converting this information into conscious vision. Closely connected to area 17 are two secondary areas surrounding the primary visual area: the parastriate area (area 18) and the pre-striate area (area 19). Area 18 is concerned with the recognition of objects, while area 19 is concerned with the recall of visual objects. The function and location of both of these areas are, however, in dispute among investigators. These three areas are very well illustrated on page 296 of Wright (1966).

A fourth cortical area, the angular gyrus, functions as the storage area for the recognition and recall of visual speech and the memory pattern of symbols of written or printed language. That is, it provides an interpretative function for symbols. The major angular gyrus is closely associated with area 19.

The iris is controlled by two sets of muscles, the sphincter and dilator. The current theory of their function is centered around the phenomenon of reciprocal innervation. Dilation is dependent on contraction of the dilator and relaxation of the sphincter. These muscles are innervated by the autonomic nervous system. The parasympathetic (involuntary) division of this system controls pupil size as a function of light intensities

and accommodation. The role of the sympathetic division in controlling pupil size is not as clear, however. The afferent pathway from the cortical center to the iris is, at present, in doubt, although the centers for the origin of pupillary dilator impulses are located in the hypothalamus.

The pupils are in a constant state of change, depending upon the changing balance between the tonus of the sphincter and dilator muscles. Because so many factors influence this balance, it is extremely difficult to isolate one from another. The various factors that influence the state of the pupils may be divided into two rough categories: (1) responses determined by light variations (light reflex) and accommodation, and (2) responses to sensory stimulation. It is the latter case that is of paramount interest in the experiment described in this paper.

Most of the experimental work that has been done since the pioneering efforts of Hess and Polt (1960) can be separated into two major categories: those that have dealt with cognitive demand, and those centered around attitude and preference. Barlow (1969), in his review of pupillometric literature noted that the former showed consistent results, while the latter yielded (as might be expected) ambiguous results. Since the present experiment properly belongs in the first category, a short resume of cognitive demand experiments would be in order.

Hess and Polt (1964), in an experiment involving multiplication problems, found that the diameter of the pupil increased with the difficulty of the problem. They concluded that pupil response in this situation was a direct reflection of neurological activity.

In a replication of this experiment, Hope (1971) substantiated the correlation of an increase in pupil diameter for correctly answered problems but found an associated decrease in pupil diameter for incorrect replies. He also found that when a subject made a correct response, the maximum dilation reached was maintained, while for an incorrect response, the diameter decreased after reaching a maximum and continued to decline through the base-line diameter into the constriction region. He interpreted this as a manifestation of cortical "overload," that is, a blocking out of the stimuli.

Kahneman and Beatty (1966) compared pupillary response in a short-term memory task with that of a long-term memory task. They found that the peak diameter reached during the report phase of the long-term task was consistently greater than for the short-term task. They concluded that an obvious mental effort was exerted by the subjects in response to the cue, and that apparently this effort is at a maximum shortly after the cue. They cautioned, however, that retrieval of information from long-term memory may not invariably elicit a greater pupillary response than short-term memory and recall.

Kahneman and Beatty (1967) conducted an audio-tonal discrimination experiment in which the subjects compared two tones and then were required to decide whether the comparison tone was higher or lower than the standard tone. They found that the magnitude of dilation increased with the difficulty of the discrimination task.

Paivio and Simpson (1968) conducted an experiment to investigate the effect on pupil diameter when an overt response indicating task fulfillment was required. They found that greater dilation occurred only in those conditions in which an overt response was required; in this case pressing a key and/or verbalizing a response. They concluded that pupillary dilation is enhanced when an overt motor response is required. This finding substantiated the findings of others (Simpson & Paivio, 1966; Hakerem & Sutton, 1966).

## II. BACKGROUND AND PURPOSE OF THE EXPERIMENT

When an aviator flies under instrument conditions, his primary reference instrument is the Vertical Gyro Indicator (VGI). This device is essentially a gyroscope aligned with the earth's surface before take-off. The VGI informs the pilot of the aircraft's pitch attitude (level, climbing or diving) and roll attitude (left or right wing down, or wings level).

It is not at all uncommon during flight for the pilot to be distracted from his flight instruments to make radio frequency changes, etc., and, upon re-scanning the flight instruments, find that the aircraft has entered into an "unusual attitude," that is, an attitude not consciously directed by the pilot. The pilot must then interpret what attitude the aircraft is in and apply the proper recovery procedure. This dual task becomes critically important when flying at low altitudes, such as making an

instrument approach, when, interestingly enough, the distractions are most numerous.

Thus it is apparent that the first task, that of correct VGI interpretation, is the key factor in a safe recovery. The experiment conducted was designed to simulate, in part, the VGI display encountered in an "unusual attitude." The purpose of the experiment was to investigate the pupillary activity prompted by the mental activity associated with the interpretation of the VGI displays.

## III. EXPERIMENTAL PROCEDURE

### A. APPARATUS

Measurements of pupil diameter were taken and recorded by a Space Sciences Model 831D television pupillometer. This device is basically a closed circuit television system employing a signal processor to measure and display pupil diameter. A chart recorder integral to the unit provides a continuous, real-time record of the pupil diameter (see Fig. 4).

The subjects were seated at the end of a table with their chin and forehead resting in an adjustable frame. The TV camera was focused on the left eye. Illumination of the eye was provided by a near-infra-red, low-intensity light source attached to the side of the camera mount.

The stimuli used in the experiment were black-and-white slides which were rear projected on a screen 36 inches from the subjects' eyes

by a KODAK Ektagraphic Model B-2 slide projector. The height of the center of the projected slides was adjusted to the level of each subject's eyes.

The experiment was performed in one end of a windowless room using black-out curtains to achieve a semi-darkened condition.

The slides used as test stimuli were photographs of the face of a VGI removed from the instrument panel of an instrument flight simulator (Link Trainer). The VGI was positioned to portray ten different flight attitudes (See App. A and Figs. 6 and 7). Six of the ten attitudes were in the inverted position, since they were hypothesized to be the most difficult to interpret, hence, evoke the greatest response.

Before and after each stimulus slide, a control slide with the numeral 5 in the center was projected on the screen for the subject to focus on. This slide served to elicit a base-line pupil diameter from which measurements of changes in diameter could be made when the stimulus slide was projected.

The slides were carefully controlled for equality in brightness and contrast to minimize the light reflex effect. Measurements of luminance were taken using a light meter to insure that both control slides and stimulus slides were of the same luminance, as far as possible. The light meter readings ranged from f3.9 to f2.9.

To provide a means of accurately event-marking the graph, the switch initiating slide changes was connected to the EVENT MARKER channel

of the pupillometer. The subjects were also provided a switch which event-marked the graph when they were ready to verbalize their interpretation of the stimulus slide.

All experimental trials were conducted at the Naval Postgraduate School Human Engineering Laboratory, Monterey, California.

## B. SUBJECTS

Twenty-one volunteer male military officers assigned to the Naval Postgraduate School were originally tested. However, due to difficulties associated with the pupillometer, the data for seven of the subjects was judged to be too unreliable to be useful. These problems will be discussed later. The remainder of this paper will, then, be based on the remaining fourteen subjects.

All the subjects tested were experienced Naval Aviators from both the Navy and the Marine Corps, enrolled as graduate students at the Naval Postgraduate School. Their average age was 29. The average number of years of designation as an aviator was six years. Their average total flight time was 1700 hours, ranging from 850 hours to 5000 hours.

Experienced pilots were selected for this experiment because of their familiarity with the function of the VGI as a result of their training and experience, thus minimizing a learning effect.

Of the fourteen subjects, half were helicopter, transport, or patrol pilots, while the remainder were fighter and attack pilots. For

the purposes of later analysis, the two groups were labeled Group A and Group B respectively. This division was not arbitrary. Transport, patrol, and helicopter pilots seldom, if ever, encounter unusual flight attitudes, particularly inverted attitudes, while fighter and attack pilots do. It was hypothesized that there should be a significant difference in pupillary response as a result.

## C. METHOD

Prior to the experiment, each subject was given a brief explanation of the equipment and the purpose of the equipment to put the subject at ease and remove some of the mystery of the equipment. The experimenter then formally read the instructions to subjects (App. D).

After the subject was seated, the chin rest was adjusted so that the head was level but comfortable. The subject was then instructed to focus on the numeral 5 projected on the screen while the camera and pupillometer were adjusted. Two practice trials were then conducted to familiarize the subject with the procedure and display.

The experiment began by having the subject focus on the numeral 5 on the control slide. The experimenter monitored the pupillary diameter until a reasonably steady diameter was apparent, then initiated a stimulus slide. As soon as the subject analyzed the attitude represented, he pressed the switch he held in his right hand and verbalized the response. The stimulus slide remained on the screen during the verbalization.

The experimenter event-marked the graph when the subject finished the verbalization and recorded the response. The experimenter then initiated a control slide, beginning the next trial. The subject was not informed of the correctness of his response.

The slide order was randomized for each subject.

## D. MEASUREMENTS

Three measurements were taken from the graph for analysis.

(1) Latency of Dilation (LD): the time (sec.) from slide initiation to maximum dilation.

(2) Base-line Diameter ($d_b$): the pupil diameter prior to initiation of a stimuli slide (usually the 3-4 sec. period prior to initiation).

(3) Maximum diameter ($d_m$): the maximum pupil diameter reached during the interpretation of the stimuli slide.

The scores for pupil diameter changes were calculated as percentages:

$$\frac{d_m - d_b}{d_b} \text{ X } 100 = \text{percent pupil diameter change.}$$

## IV. DISCUSSION AND RESULTS

The pupil reached maximum dilation an average of 0.8 seconds before the subjects pressed the MARK EVENT button and began verbalizing their analysis of the stimulus. This was of interest since it was anticipated that maximum dilation would occur at the moment of event-marking. Since the subject's chin, and consequently his head, would move while talking, the eye moved out of optimum camera focus. The chart output for the verbalization phase was ignored as a consequence. After verbalization, the diameter typically had returned to the base-line value.

Since the slide projector required 1.0 second to complete a slide change, a momentary light reflex occurred. This reflex was very noticeable on the graph. Since the pupil diameter typically returned to the base-line level very shortly after completion of the change, and then began a steady increase to a maximum diameter, the slide changing appeared to have no appreciable confounding effect. Thus, the precaution of insuring equal luminance of control slides and stimuli slides as recommended by Woodmansee (1966) was vindicated.

The analysis of variance of the two measures, Table I, shows that no significance was found for the percent pupil diameter change (PPDC), while the latency of dilation (LD) shows significance for the slides (VGI displays) main effect. To investigate this significance further, the mean LD was plotted with the slides ranked according to increasing mean LD of all subjects (Fig. 1).

## TABLE I.

## ANALYSIS OF VARIANCE SUMMARY TABLE

### Percent Pupil Diameter Change (PPDC)

| | df | MS | F | P |
|---|---|---|---|---|
| Between Subjects | | | | |
| Pilot Group (G) | 1 | 196.59 | 0.30 | (NS) |
| Error | 12 | 654.64 | | |
| Within Subjects | | | | |
| Slides (S) | 9 | 90.22 | 0.59 | (NS) |
| S X G | 9 | 114.20 | 0.75 | (NS) |
| Error | 108 | 151.71 | | |
| Total | 139 | | | |

### Latency of Dilation (LD)

| | df | MS | F | P |
|---|---|---|---|---|
| Between Subjects | | | | |
| Pilot Groups (G) | 1 | 19.61 | 2.17 | (NS) |
| Error | 12 | 9.02 | | |
| Within Subjects | | | | |
| Slides (S) | 9 | 4.67 | 4.31 | .0001 |
| S X G | 9 | 1.75 | 1.61 | (NS) |
| Error | 108 | 1.08 | | |
| Total | 139 | | | |

(NS = not significant $p > .05$)

It was noted that the inverted VGI displays appeared to evoke a greater mean LD than the upright VGI displays. For PPDC note (Fig. 2) that no clear pattern emerges from the responses.

The mean LD for the inverted VGI displays was 3.40 seconds, while the mean LD for the upright VGI displays was 2.57 seconds. The null hypothesis that the means are equal could be rejected at the .01 level ($t=3.46$, $df=138$). Using PPDC as the measure, the mean PPDC for the upright VGI displays was 10.47 and for the inverted VGI displays was 9.33. The null hypothesis of equality of the means could not be rejected ($t=0.48$, $df=138$).

Each group was then examined separately to determine if there was a significant difference in response between the inverted and upright VGI displays. Using LD as the measure, both groups demonstrated a significant difference:

<u>Group A</u>: inverted mean = 3.85

upright mean = 2.82

Reject $H_0$: means are equal at .01 level ($t=2.51$, $df=68$)

<u>Group B</u>: inverted mean = 2.94

upright mean = 2.32

Reject $H_0$ at .05 level ($t=2.58$, $df=68$)

Using PPDC as the measure, neither group demonstrated a significant difference in means:

Group A: inverted mean = 11.06

upright mean = 10.85

Cannot reject $H_0$ (t=0.06, df=68)

Group B: inverted mean = 7.61

upright mean = 10.09

Cannot reject $H_0$ (t=0.79, df=68)

Disagreement between the two measures was also found when the data was tested to determine if there was a difference in the responses of the two groups for (1) the upright VGI displays, and (2) the inverted VGI displays. Using LD as the measure, the following results were obtained:

Upright VGI Displays: Group A mean = 2.82

Group B mean = 2.32

Can reject $H_0$: means are equal at .01 level (t=2.78, df=54)

Inverted VGI Displays: Group A mean = 3.85)

Group B mean = 2.94

Can reject $H_0$ at .01 level (t=2.53, df=82)

Using PPDC as the measure, the following results were obtained:

Upright VGI Displays: Group A mean = 10.85

Group B mean = 10.09

Cannot reject $H_0$ (t=0.18, df=54)

Inverted VGI Displays: Group A mean = 11.06

Group B mean = 7.61

Cannot reject $H_0$ (t=1.28, df=82, p .20)

Paivio and Simpson (1968) suggested that the latency of dilation, i.e., the time from presentation of the stimulus until maximum pupil dilation is reached, may be a more sensitive indicator of mental effort than pupil diameter increase. This was substantiated by Colman and Paivio (1969). They also demonstrated that dilation during a cognitive task is enhanced when the subject is required to make an overt response indicating task fulfillment. It can thus be reasonably contended that if pupil diameter change had been significant in the present experiment, some doubts could have been raised about the validity of that significance. The fact that pupil diameter increase was not significant but the latency of dilation was, tends to support Simpson and Paivio's contention (1968) that latency of dilation is, in fact, a more sensitive indicator of the processing effort.

Woodmansee (1966) recommended that pupillometric experimenters check for arousal decrement of subjects across trials. This arousal decrement, he noted, can occur as the result of boredom, fatigue or adaptation. In the present experiment, this was eliminated (as recommended by Pratt (1969)) by using, as the dilation score, the percent change of diameter from control slide ($d_b$) to maximum diameter occurring during stimulus slide presentation ($d_m$). Fig. 3 is a plot of the percent of change of the base-line diameter across trials with trial 1 as the base figure. Note that most of the decrease occurred during the initial trials of the experiment. This appears to indicate that the subjects were

highly excited at the beginning of the experiment due to the newness of the experiment which even the instructions, demonstrations, and two practice trials could not eliminate. After viewing a few of the early slides, the subjects had apparently adjusted to the experiment and further changes were more gradual.

During the experiment, two major procedural problems with the pupillometer arose which merit discussion and hopefully may aid other experimenters in their research efforts using the same instrument.

It was observed on a number of occasions that obtaining an optimal crescent and black line on the TV monitor was almost impossible in spite of adjusting the camera viewing angle, the f-stop, and the light source. This was particularly true with subjects with light colored irises. Subjects with dark irises presented almost no problem.

Subjects with long eyelashes or eyelashes that partially covered the iris prohibited obtaining accurate pupil measurement. The solution to this problem is a modification of the camera mount so that the camera can be tilted up slightly.

Note: Slides 1-4 are upright VGI displays
Slides 5-10 are inverted VGI displays

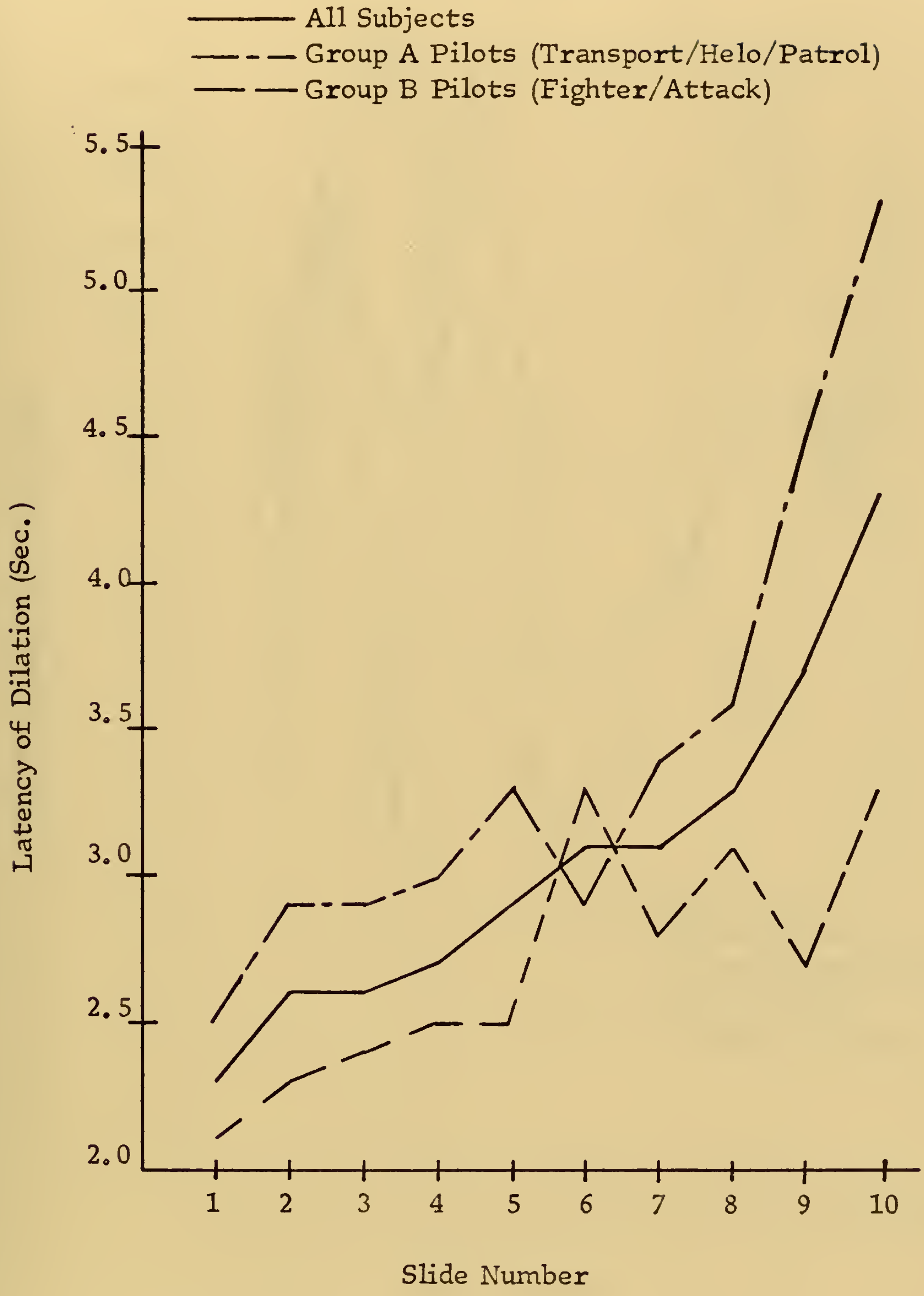


FIGURE 1. LATENCY OF DILATION (LD)

Note: Slides 1-4 are upright VGI displays
Slides 5-10 are inverted VGI displays

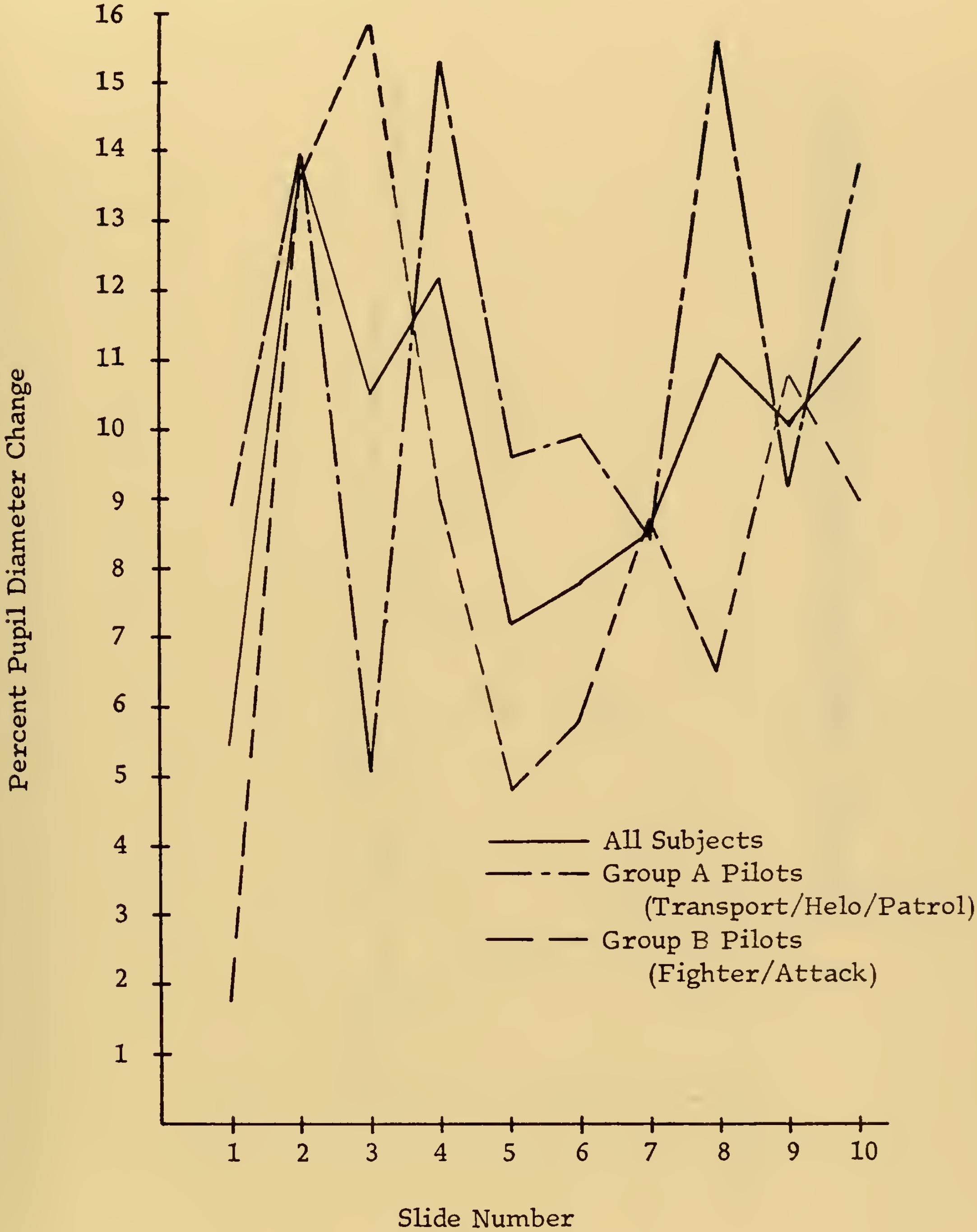


FIGURE 2. PERCENT PUPIL DIAMETER CHANGE (PPDC)

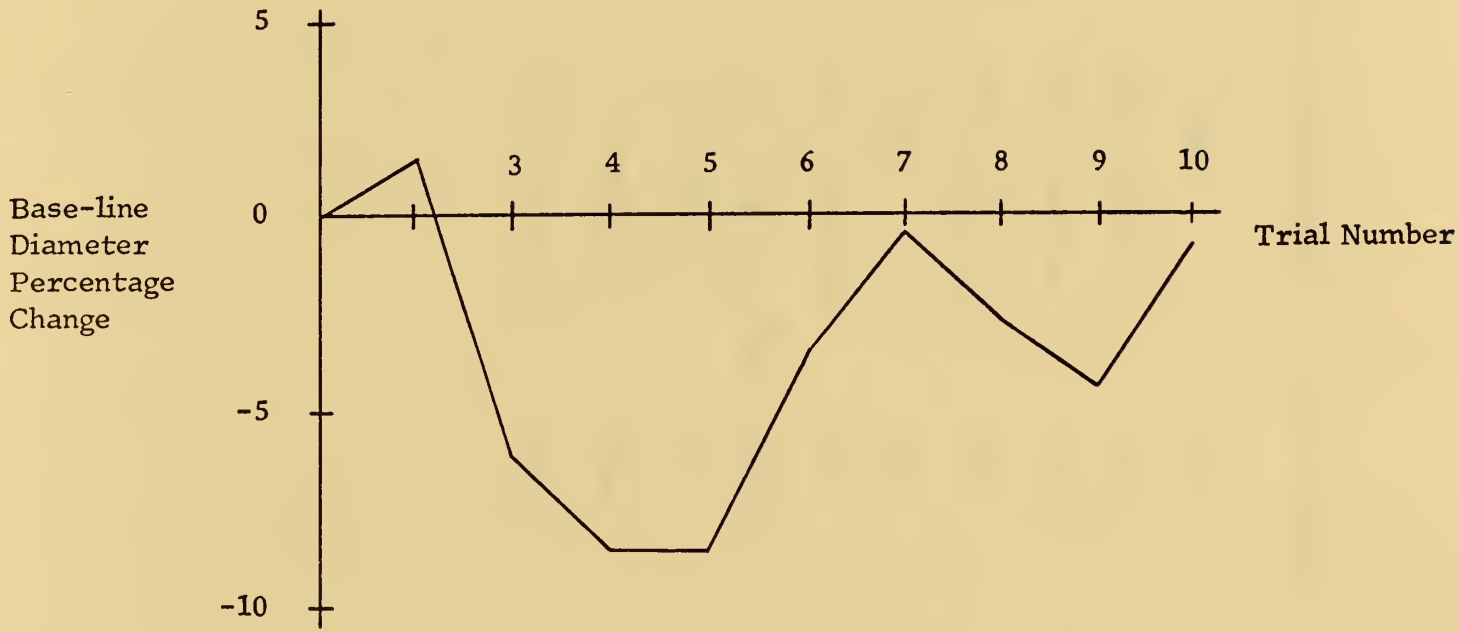


FIGURE 3. BASE-LINE DIAMETER PERCENTAGE CHANGE

## APPENDIX A

### SIMULATED AIRCRAFT ATTITUDES USED AS STIMULI

| Slide Number | Wing Position | Nose Position | Upright/ Inverted |
|---|---|---|---|
| 1 | Level | Up | Upright |
| 2 | Rt. Wing Down | Level | Upright |
| 3 | Lt. Wing Down | Level | Upright |
| 4 | Rt. Wing Down | UP | Upright |
| 5 | Level | Up | Inverted |
| 6 | Lt. Wing Down | Up | Inverted |
| 7 | Rt. Wing Down | Level | Inverted |
| 8 | Rt. Wing Down | Up | Inverted |
| 9 | Rt. Wing Down | Down | Inverted |
| 10 | Lt. Wing Down | Down | Inverted |

## APPENDIX B

## TABLES

### TABLE II. PERCENT PUPIL DIAMETER CHANGE

| | | Slide Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subject | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Group A | 1 | 18.8 | 20.0 | 0.0 | 26.7 | 19.4 | 11.4 | 31.4 | 39.4 | 15.2 | 25.7 |
| | 2 | 22.2 | 15.4 | 10.0 | 70.6 | 14.3 | 71.4 | -6.1 | 16.7 | 8.7 | -7.1 |
| | 3 | 12.9 | 22.6 | 7.7 | -3.4 | 12.8 | -17.2 | 2.3 | 9.1 | 7.5 | 10.5 |
| | 4 | 2.6 | 2.4 | 2.6 | 0.0 | -2.7 | 2.6 | 4.9 | 10.0 | 7.5 | 0.0 |
| | 5 | 0.0 | 20.0 | 8.7 | 7.4 | 8.2 | 3.7 | 8.0 | 15.4 | 13.6 | 42.9 |
| | 6 | 6.1 | 13.3 | 3.2 | 6.1 | 13.3 | -2.9 | 16.1 | 16.7 | 10.0 | 20.0 |
| | 7 | 0.0 | 4.0 | 3.9 | 0.0 | 1.9 | 0.0 | 2.0 | 2.1 | 1.9 | 3.8 |
| Group B | 8 | 15.4 | 41.4 | 8.7 | 2.4 | 30.0 | 19.2 | 20.0 | 8.6 | 14.3 | 13.3 |
| | 9 | 0.0 | 7.1 | 0.0 | 16.1 | 7.4 | 0.0 | 3.5 | 3.1 | 2.6 | 3.6 |
| | 10 | 0.0 | 44.0 | 64.0 | 29.1 | 8.0 | 2.9 | 22.6 | 12.5 | 20.0 | 11.1 |
| | 11 | -13.6 | -9.1 | 7.5 | -5.0 | 5.3 | 5.6 | 5.0 | -2.4 | 7.3 | 2.2 |
| | 12 | 8.0 | -11.1 | 7.7 | 9.7 | -23.1 | 3.0 | 3.3 | 13.8 | -3.6 | 7.1 |
| | 13 | 3.2 | 17.4 | 16.7 | 4.5 | 12.0 | 6.7 | 0.0 | 10.7 | 26.1 | 16.0 |
| | 14 | 0.0 | 5.9 | 6.3 | 6.3 | -5.9 | 3.1 | 6.3 | 0.0 | 8.8 | 9.7 |

## TABLE III. LATENCY OF DILATION

| | | Slide Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Group A | Subject | | | | | | | | | | |
| | 1 | 3.2 | 2.8 | 3.9 | 3.1 | 3.7 | 2.3 | 5.2 | 3.6 | 6.3 | 3.7 |
| | 2 | 2.1 | 2.0 | 2.4 | 2.6 | 3.8 | 3.4 | 2.6 | 2.7 | 4.3 | 3.2 |
| | 3 | 2.2 | 2.7 | 3.3 | 2.5 | 2.1 | 2.2 | 2.8 | 3.1 | 2.3 | 2.5 |
| | 4 | 2.0 | 2.3 | 1.7 | 2.0 | 2.4 | 1.9 | 2.0 | 2.2 | 2.6 | 2.3 |
| | 5 | 2.0 | 3.0 | 2.5 | 3.2 | 2.1 | 5.1 | 2.1 | 4.9 | 3.2 | 5.9 |
| | 6 | 3.9 | 4.4 | 3.1 | 4.5 | 4.6 | 2.8 | 5.2 | 5.1 | 10.4 | 11.8 |
| | 7 | 2.2 | 3.3 | 3.2 | 3.0 | 4.3 | 2.8 | 4.0 | 3.6 | 3.4 | 7.4 |
| Group B | 8 | 1.5 | 2.6 | 2.1 | 2.0 | 3.4 | 5.1 | 4.2 | 5.7 | 3.2 | 5.5 |
| | 9 | 1.4 | 1.2 | 1.4 | 1.4 | 1.5 | 1.2 | 1.4 | 1.6 | 1.3 | 1.3 |
| | 10 | 2.3 | 2.2 | 1.9 | 2.1 | 1.6 | 2.4 | 2.8 | 1.9 | 2.5 | 2.2 |
| | 11 | 1.9 | 2.2 | 3.1 | 2.1 | 2.4 | 2.6 | 2.8 | 2.6 | 2.7 | 2.8 |
| | 12 | 3.0 | 3.3 | 3.2 | 3.8 | 2.8 | 3.6 | 3.4 | 3.0 | 3.1 | 3.6 |
| | 13 | 2.3 | 2.2 | 2.3 | 2.7 | 3.7 | 2.6 | 2.8 | 3.0 | 3.0 | 3.4 |
| | 14 | 2.5 | 2.4 | 2.9 | 3.1 | 2.0 | 5.5 | 2.4 | 3.6 | 2.9 | 4.4 |

TABLE IV. BASE-LINE DIAMETER PERCENTAGE CHANGE

| | | Trial Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Group A | Subject | | | | | | | | | | |
| | 1 | 0.0 | 0.0 | 0.0 | -8.6 | -14.3 | -5.7 | -5.7 | -11.4 | 2.9 | 0.0 |
| | 2 | 0.0 | -30.3 | -39.4 | -36.4 | -15.2 | -48.5 | -18.2 | -36.4 | -9.1 | -21.2 |
| | 3 | 0.0 | 10.3 | 2.6 | -20.5 | 0.0 | -2.6 | -20.5 | -15.4 | -25.7 | -25.7 |
| | 4 | 0.0 | -5.1 | -2.6 | 0.0 | 2.6 | 5.1 | 0.0 | 2.6 | 5.1 | 10.2 |
| | 5 | 0.0 | -11.1 | -3.7 | 3.7 | -7.4 | -7.4 | -7.4 | 0.0 | -18.5 | -14.8 |
| | 6 | 0.0 | -9.1 | -9.1 | -9.1 | -6.1 | -9.1 | -6.1 | -9.1 | 0.0 | 3.0 |
| | 7 | 0.0 | 3.9 | 2.0 | 2.0 | -2.0 | -2.0 | -5.9 | -2.0 | 3.9 | 5.9 |
| Group B | 8 | 0.0 | 16.7 | -13.3 | -3.3 | -33.3 | 35.7 | 63.4 | 33.3 | 16.6 | 53.4 |
| | 9 | 0.0 | 22.6 | -6.4 | -12.9 | 6.4 | -9.7 | 3.2 | -3.2 | -9.7 | -6.4 |
| | 10 | 0.0 | 29.1 | 0.0 | -12.9 | -19.3 | 12.9 | 3.2 | -19.3 | -19.3 | -19.3 |
| | 11 | 0.0 | -11.1 | -11.1 | -2.2 | -11.1 | -6.7 | -20.0 | -8.9 | -26.7 | -15.5 |
| | 12 | 0.0 | 6.9 | 3.4 | -10.3 | -13.8 | 13.8 | -3.4 | -3.4 | -6.9 | -10.3 |
| | 13 | 0.0 | 0.0 | -8.0 | -8.0 | -12.0 | -28.0 | 12.0 | 28.0 | 20.0 | 24.0 |
| | 14 | 0.0 | -3.1 | 0.0 | 0.0 | 9.4 | 6.2 | 0.0 | 9.4 | 6.2 | 6.2 |

## APPENDIX C

## FIGURES

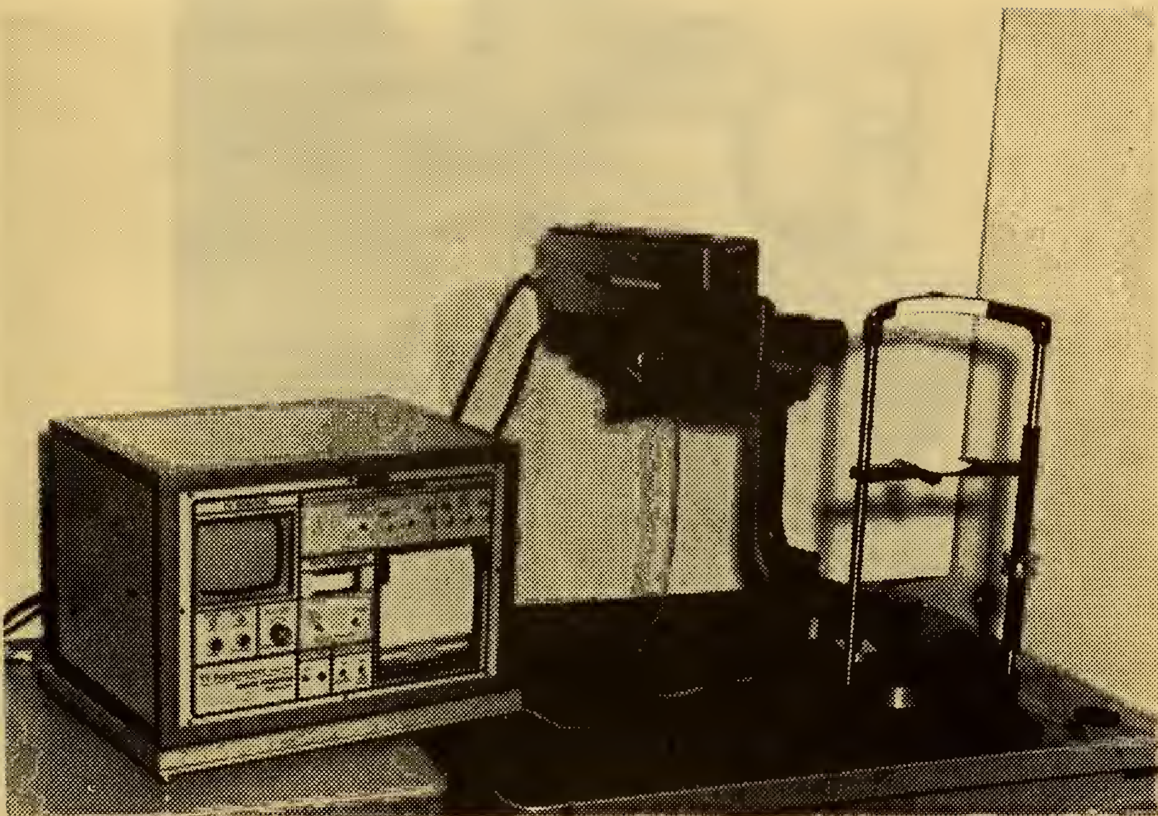

FIGURE 4. THE SPACE SCIENCE MODEL 831D TELEVISION PUPILLOMETER

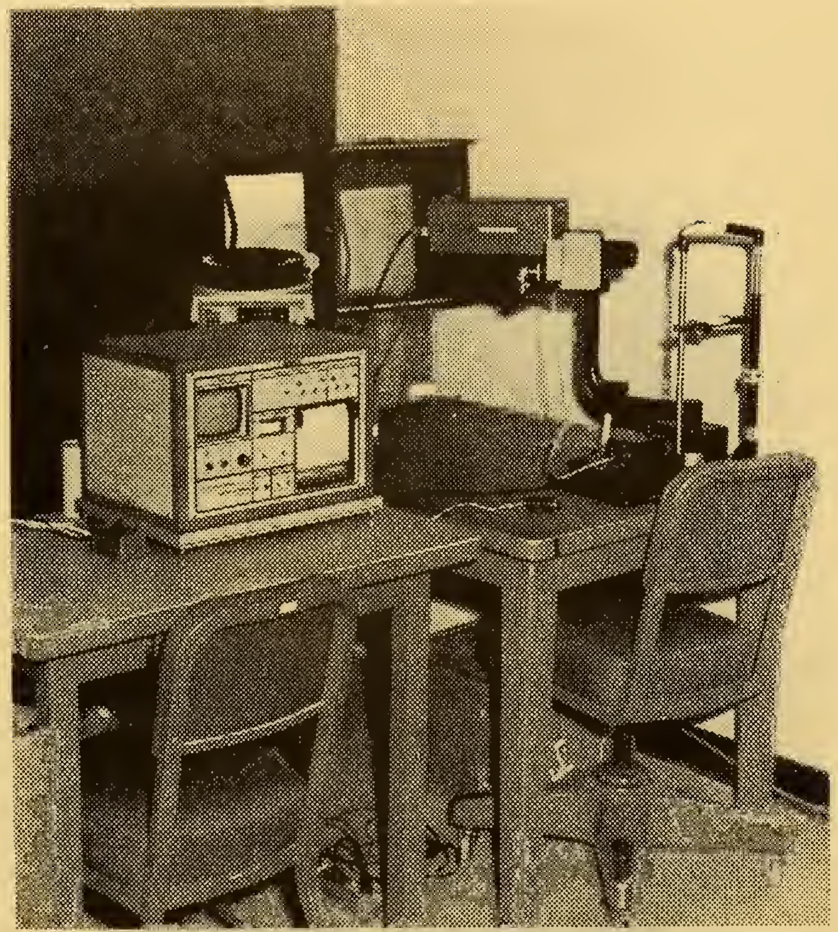

FIGURE 5. THE PUPILLOMETER AS SET UP WITH THE SLIDE PROJECTOR AND SCREEN

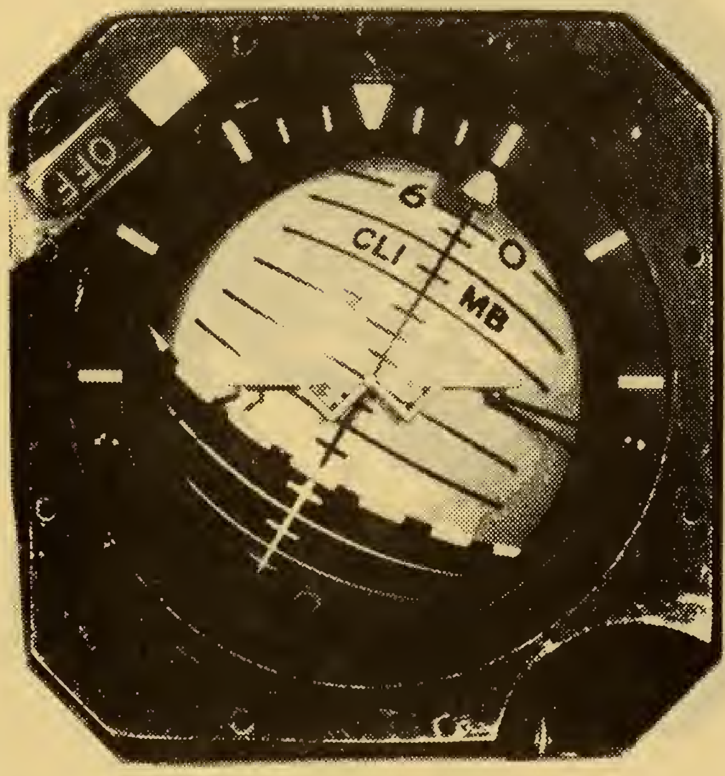


FIGURE 6. THE VERTICAL GYRO INDICATOR (VGI) IN THE UPRIGHT, NOSE UP, LEFT WING DOWN POSITION


FIGURE 7. THE VERTICAL GYRO INDICATOR (VGI) IN THE INVERTED, NOSE DOWN, RIGHT WING DOWN POSITION

## APPENDIX D

## INSTRUCTIONS FOR SUBJECTS

THIS IS AN EXPERIMENT TO TEST EYE RESPONSE TO VISUAL STIMULI. YOU WILL BE SEATED AT THE END OF THE TABLE WITH YOUR CHIN AND FOREHEAD RESTING IN THE FRAME. WHEN YOU ARE READY, A SLIDE OF A VGI WILL BE PROJECTED ON THE SCREEN. WHEN YOU HAVE ANALYZED THE VGI; THAT IS, DETERMINED THE ATTITUDE OF THE SIMULATED AIRCRAFT, PRESS THE BUTTON YOU HOLD IN YOUR HAND. THEN VERBALLY DESCRIBE THE AIRCRAFT ATTITUDE IN THE FOLLOWING TERMS:

(1) NOSE UP/DOWN/LEVEL

(2) INVERTED/UPRIGHT

(3) LEFT WING DOWN/RIGHT WING DOWN/WINGS LEVEL

THE ORDER IN WHICH YOU VERBALIZE THESE IS NOT IMPORTANT--BUT PLEASE STATE ALL THE DESCRIPTORS.

AFTER VERBALIZING THE RESPONSE, A FOCUSING SLIDE WITH THE NUMBER 5 IN THE CENTER WILL APPEAR. PLEASE FOCUS ON THE NUMBER. THE NEXT SLIDE WILL THEN BE PRESENTED.

THE PUPILLOMETER IS VERY SENSITIVE TO HEAD MOVEMENTS, SO PLEASE DO NOT MOVE YOUR HEAD DURING THE COURSE OF THE EXPERIMENT.

WE WILL NOW RUN THROUGH A TEST TRIAL OF THE EXPERIMENT TO FAMILIARIZE YOU WITH THE PROCEDURE AND THE DISPLAY.

ANY QUESTIONS?

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13. ABSTRACT


An indirect measurement of mental effort in interpreting an aircraft instrument was made using changes in pupil diameter and the latency of dilation as measures. Significance was found in latency of dilation across levels of interpretation difficulty, while no significance was found for percent changes in pupil diameter.

Results also showed a moving base-line pupil diameter for all subjects across trials suggesting arousal decrement for the first half of the experiment, with a lesser effect for the latter half of the experiment.


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